

TITLE OF THE INVENTION

POLISHING PAD AND METHOD OF MANUFACTURING SEMICONDUCTOR  
DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2003-029560, filed February 6, 2003,  
the entire contents of which are incorporated herein by  
reference.

10                           BACKGROUND OF THE INVENTION

1. Field of the Invention

          The present invention relates to a polishing pad  
and a method of manufacturing a semiconductor device,  
and in particular, to a polishing pad employed in CMP  
15   (Chemical Mechanical Polishing) and the method of  
manufacturing a semiconductor device using the  
polishing pad.

2. Description of the Related Art

          In recent years, concomitant with the trend to  
20   further increase the integration of LSIs, the  
techniques to further refine the wirings are now being  
rapidly advanced to such an extent that the design rule  
thereof is now getting as small as less than 0.1  $\mu\text{m}$ .  
Additionally, in order to alleviate the delay of RC  
25   wiring, it is considered imperative to employ a novel  
material. Under the circumstances, it is now being  
tried to employ Cu which is low in electrical

resistance ( $\rho$ : 1.8  $\mu\Omega\text{cm}$ ) as a conductive material, and to employ an insulating film of low relative dielectric constant ( $k$ : <2.5) as an electrical insulating material.

5           Cu wirings are, in most cases, buried in an insulating film by using CMP technique so as to be formed as a damascene wiring. This CMP is generally performed in such a way that slurry is fed to the surface to be polished (hereinafter referred to as  
10           polishing surface) and a polishing pad is contacted with the polishing surface and rotated to perform the polishing. On this occasion, the polishing performance is greatly influenced by the quantity of slurry that can be retained by the surface of the polishing pad as  
15           well as by the grain size of the abrasive grains contained in the slurry.

          For example, if the polishing is performed by using slurry containing relatively coarse abrasive grains, scratches are generated on the polishing  
20           surface after polishing. At present, although the diameter of the primary particles of colloidal silica produced by using sol-gel method can be controlled to 0.02  $\mu\text{m}$  (1 $\sigma$ : 0.005  $\mu\text{m}$ ), the primary particles flocculate depending on the conditions particularly  
25           when slurry having such a colloidal silica dispersed in a solvent is left to stand, thereby allowing coarse secondary particles having a maximum diameter of 10  $\mu\text{m}$

or more to grow. As a matter of fact, when coarse particle having a diameter of 1  $\mu\text{m}$  or so is existed in the slurry, it will give great influences on the generation of scratch.

5           Even when the CMP is performed by using a slurry having no abrasive grain included therein, it is quite conceivable that the particles having a particle diameter of the order of microns that may be originated from the peeling of semiconductor substrate, dust and  
10           reaction products may generate scratches.

          In any case, the scratch that has been generated on the polishing surface as a result of the polishing thereof may generate short of circuit, thereby inviting the malfunction of a semiconductor device. Therefore,  
15           it is desired that only relatively small particles or effective particles which are capable of contributing to the polishing are retained on the surface of a polishing pad, and that coarse particles whose diameter is larger than required as well as any factor that may  
20           generate flaw such as dust are quickly removed from the surface of a polishing pad.

          Further, an insulating film having a low relative dielectric constant in which a conductive material such as Cu is to be buried is, in most cases, formed of  
25           a hydrophobic material containing an organic component. Therefore, on the occasion of burying a conductive material to expose the surface of this film having

a low relative dielectric constant, polishing friction increases, thus occurring the peeling of the film. Since the substances created from the peeling of the film have almost the same size as that of coarse  
5 particles existing in the slurry, they may generate scratches on the polishing surface resulting from the polishing process. Moreover, since the hydrophobic material is liable to adsorb coarse particles, scratches may generate more vigorously or may become  
10 a nucleus through which the peeling of film generates.

Although it is possible to suppress scratches by using a soft polishing pad, it may become difficult to meet the severe design rule of semiconductor restricting that the erosion should be confined to not  
15 more than 300 angstroms. For this reason, a hard polishing pad having a compression elastic modulus of 150 MPa or more has been employed at present.

The conventional hard polishing pad is formulated based mainly on reducing the erosion as seen in IC1000  
20 (trade name; Rodel Nitta Co., Ltd.) for instance. In such a conventional hard polishing pad, the retention of abrasive grains is achieved by the inclusion of cells (voids) or a water-soluble solid material, wherein the volume of voids or solid material is set to  
25 higher than 5% by volume based on the entire volume of matrix of polishing pad.

There has been also proposed to employ a polishing

pad wherein the number of large and small cells per unit area is regulated. Specifically, the number of closed cells having an average pore diameter of 0.3 mm or more is regulated to one/cm<sup>2</sup> or more and the number of closed cells having an average pore diameter of 0.1 mm or less is regulated to 100/cm<sup>2</sup> or less.

However, when the polishing is performed using such a polishing pad, it has been considered difficult to sufficiently reduce the generation of scratches on the polishing surface in the polishing process.

Incidentally, in the case of a polishing pad containing abrasive grains, it is proposed to regulate the ratio of cells in the polishing pad to 5% by volume or more in order to enhance the dispersibility of the abrasive grains and to secure a stable polishing performance. Since this polishing pad is a fixed abrasive grain-containing polishing pad, the polishing is performed by not supplying a slurry but supplying only water. Accordingly, in the employment of such a polishing pad, not only the quantity of slurry retained on the surface of polishing pad but also the interaction of slurry with polishing pad are not taken into consideration, and as a matter of fact, are no longer required to be taken into consideration in executing the polishing.

#### BRIEF SUMMARY OF THE INVENTION

A CMP pad according to one embodiment of the

present invention is abrasive-free and comprises:

cells and/or a recessed portion-forming material both having an average diameter ranging from 0.05 to 290  $\mu\text{m}$  and occupying a region ranging from 0.1% by volume to 5% by volume based on an entire volume of the pad; and

an organic material.

A method for manufacturing a semiconductor device according to one embodiment of the present invention comprises:

forming a treating film above a semiconductor substrate; and

subjecting the treating film to polishing treatment while feeding a slurry onto the treating film, the polishing pad comprising a matrix, and cells and/or a recessed portion-forming material both having an average diameter ranging from 0.05 to 290  $\mu\text{m}$ , dispersed in the matrix, and occupying a region ranging from 0.1% by volume to 5% by volume based on an entire volume of the pad, the matrix having a major surface which faces the treating film and has a roughness of 5  $\mu\text{m}$  or less.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIGS. 1A and 1B respectively shows a cross-sectional view schematically illustrating the features of the section and surface of a polishing pad;

FIGS. 2A to 2C are cross-sectional views each

illustrating the manufacturing process of  
a semiconductor device according to one embodiment of  
the present invention;

FIG. 3 is a perspective view illustrating the  
5 manufacturing process of a semiconductor device accord-  
ing to one embodiment of the present invention; and

FIGS. 4A and 4B are cross-sectional views each  
illustrating the manufacturing process of a  
semiconductor device according to another embodiment of  
10 the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

Next, embodiments according to the present  
invention will be explained in detail as follows.

It has been found out by the present inventors  
15 that in order to enable the slurry that has been fed  
onto the surface of a polishing pad to be effectively  
applied to a surface to be treated (hereinafter being  
referred to simply as a treating surface) and to carry  
out the polishing of the treating surface while  
20 suppressing the generation of scratches on the treating  
surface, cells and/or a recessed portion-forming  
material, both being dispersed in the matrix of the  
polishing pad, should be controlled and optimized with  
respect to the ratio of occupying region and average  
25 diameter thereof. Incidentally, by the term  
"dispersion", it is intended to mean that cells and/or  
a recessed portion-forming material are distributed

throughout the matrix while substantially retaining their inherent individual dimension without being flocculated with each other.

5 Further, by the term "recessed portion-forming material", it is intended to indicate a water soluble solid material which can be dissolved in water as it is contacted with water during the polishing operation, thereby enabling recessed portions to be formed on the surface of the polishing pad. In this case, the  
10 recessed portions formed on the surface of the polishing pad may be the traces of the water soluble solid materials. In the interior of the polishing pad however, the water soluble solid materials are left remained as they are.

15 When the ratio of region occupied by the cells and/or a recessed portion-forming material is confined within a prescribed range, the polishing pad is enabled to have the following functions. Namely, it becomes possible, due to the provision of such cells, to enable  
20 the slurry to be reliably retained on the surface of the polishing pad, thus providing appropriate flexibility to the polishing pad. Among the water soluble solid materials, those existing on the surface of the polishing pad function in the same manner as the  
25 aforementioned cells, while the others existing in the interior of the polishing pad function so as to provide the polishing pad with an appropriate hardness.



FIGS. 1A and 1B are cross-sectional views each schematically illustrating the features of the section and surface of a polishing pad, wherein FIG. 1A shows the features before the conditioning step, while  
5 FIG. 1B shows the features after the conditioning step.

As shown in FIG. 1A, regions 11 consisting of cells and/or water soluble solid material are dispersed throughout the matrix 10 made of an organic material. The surface of the polishing pad is constituted not  
10 only by step portions 12 which are caused to generate due to the existence of aforementioned regions 11, but also by field portions 13. The height and density of the step portions 12 are determined depending on the size and density of the regions 11 dispersed in the  
15 polishing pad. The field portions 13 may be assumed as being a major surface of the matrix, which faces a treating film during the polishing process.

As a result of conditioning conducted on the surface of polishing pad, fine roughness is generated  
20 on the surface of the field portions 13 as shown in FIG. 1B. The surface roughness Ra of the polishing pad should be confined to 5  $\mu\text{m}$  or less in general, more preferably within the range of 1 to 3  $\mu\text{m}$ . If the conditioning of the polishing pad is not performed,  
25 the surface roughness Ra of the polishing pad would become as small as 0.05  $\mu\text{m}$  or less, so that it may become difficult to sufficiently retain

the slurry. Irrespective of the kind of the slurry, the surface roughness Ra of the polishing pad after the conditioning should preferably be confined within the aforementioned range. Namely, in order to enhance the interaction between the slurry and the surface of the polishing pad by rendering the surface of the polishing pad hydrophilic, even when slurry not containing abrasive grains is employed, the surface roughness Ra should preferably be confined to 5  $\mu\text{m}$  or less.

In particular, when slurry containing abrasive grains is employed, it is more likely that scratches are easily formed on the polishing surface during the polishing process if the polishing pad which is capable of easily retaining coarse abrasive grains is employed. One example of such a polishing pad is one which includes therein an excessive number of cells or water soluble solid materials. A polishing pad having retention sites for coarse particles on the surface thereof, for example, a polishing pad having closed cells having a diameter of 0.3 mm or more also makes it difficult to suppress the generation of scratches.

In the case of the polishing pad according to the embodiments of the present invention, what is distributed throughout the matrix of polishing pad is merely a region consisting of cell and/or a water soluble solid material each having a predetermined

diameter, and hence abrasive grains are not included therein. Namely, according to one embodiment of the present invention, the polishing pad is defined as comprising cells and/or a water soluble solid material both having an average diameter ranging from 0.05  $\mu\text{m}$  to 290  $\mu\text{m}$  and occupying a region ranging from 0.1% by volume to 5% by volume based on an entire volume of the polishing pad, and the balance formed of an organic material, thereby making it possible to suppress the generation of scratches on a polished surface.

An average diameter of the water soluble solid material is intended to mean an average diameter of water soluble solid particles included in a polishing pad, whereas an average diameter of the cells is intended to mean a value which can be obtained from the measurement of cells which can be observed, by SEM, on the surface of a polishing pad or on the cross-section of a polishing pad that can be obtained by cutting the polishing pad.

The matrix is generally constituted by a solidified body of an organic material because of easiness in molding it into a desired configuration and in providing it with a suitable degree of hardness and elasticity. As for the examples of organic material, they include thermoplastic resins, elastomers, rubber and curable resins (resins that can be cured by the effects of heat or light, such as thermocurable resin,

photo-curable resin). These materials can be employed singly or in any combination thereof.

As for specific examples of the thermoplastic resins, they include, for example, 1,2-polybutadiene resin, ethylene-vinyl acetate copolymer, polyolefin resin such as polyethylene, styrene-based resin such as polystyrene and ABS resin, polyacrylic resin {(metha)acrylate-based resin}, vinyl ester-based resin (excluding acrylic resin), polyester-based resin, polyamide-based resin and polyacetal resin.

As for specific examples of the elastomers, they include, for example, diene elastomer; polyolefin elastomer (TPO); styrene type block copolymer-based elastomer such as styrene-butadiene-styrene block copolymer (SBS) and the hydrogenated block copolymer thereof (SEBS); thermoplastic elastomer such as thermoplastic polyurethane-based elastomer (TPU), thermoplastic polyester-based elastomer (TPEE) and polyamide-based elastomer (TPAE); silicone resin-based elastomer; and fluororesin-based elastomer.

As for specific examples of the rubber, they include, for example, butadiene rubber (high cis-butadiene rubber, low cis-butadiene rubber, etc.), isoprene rubber, styrene-butadiene rubber, conjugated diene-based rubber such as styrene-isoprene rubber, nitrile-based rubber such as acrylonitrile-butadiene rubber, acrylic rubber, ethylene-propylene rubber,

ethylene- $\alpha$ -olefin-based rubber such as ethylene-propylene-diene-based rubber, butyl rubber, silicone rubber, fluorine-containing rubber, etc.

As for specific examples of the curable resins, they include, for example, urethane resin, epoxy resin, acrylic resin, unsaturated polyester resin, polyurethane-urea resin, urea-based resin, silicon-based resin, phenolic resin and vinyl ester resin.

These organic materials may be modified by the introduction thereto of acid anhydride group, carboxylic group, hydroxyl group, epoxy group or amino group. It is possible, by this modification, to adjust the affinity of these organic materials to water soluble solid materials to be discussed hereinafter or to slurry.

Although these organic materials can be partially or entirely cross-linked so as to turn them into a crosslinked polymer, they may be in the form of non-crosslinked polymer. Further, the matrix may be constituted by only a crosslinked polymer or by a mixture consisting of a crosslinked polymer and a non-crosslinked polymer. As for the method of crosslinking, there is not any particular limitation and hence it may be a chemical crosslinking where organic peroxide, sulfur or a sulfur compound is employed, or a radiation-induced crosslinking where the irradiation of electron beam is utilized.

By the term "water soluble" in the expression of "water soluble solid material", it is intended to denote the characteristics of a substance that when it is contacted with water, it can be released from the matrix. Therefore, the scope of the water soluble solid material include not only substances which are soluble in water such as water soluble polymers but also substances such as water-absorbing resin which swells (is gelled) quite easily as they are contacted with water and hence can be easily released from the matrix. As explained hereinafter, this water soluble solid material is formed of particles of predetermined size and usually dispersed throughout the matrix. This water soluble solid material may be useful irrespective of the kind thereof, i.e. organic or inorganic.

As for the examples of organic water soluble solid material, they include dextrin, cyclodextrin, mannitol, sugars (lactose), cellulose (hydroxypropyl cellulose, methyl cellulose, etc.), starch, protein, polyvinyl alcohol, polyvinyl pyrrolidone, polyvinyl sulfonate, polyacrylic acid, polyethylene oxide, water soluble photosensitive resin, sulfonated polyisoprene, etc.

As for the examples of inorganic water soluble solid material, they include potassium acetate, potassium nitrate, potassium carbonate, potassium bicarbonate, potassium bromide, potassium phosphate, potassium sulfate, etc.

Since the organic water soluble solid material as well as the inorganic water soluble solid material are soluble in water, they are incapable of polishing a treating substrate.

5           For the purpose of adjusting the elution of these water soluble solid materials from the matrix, these water soluble solid materials may be subjected to a coupling treatment and/or a coating treatment.

10           These water soluble solid materials can be suitably selected depending on the combination thereof with the matrix and employed singly or in combination of two or more. In particular, it is preferable to employ, as a matrix, at least one selected from the group consisting of 1,2-polybutadiene resin, ethylene-  
15 vinyl acetate copolymer, polyethylene, polyester resin, diene elastomer, polyolefin elastomer, styrene type block copolymer-based elastomer, thermoplastic polyurethane-based elastomer, conjugated diene-based rubber, ethylene- $\alpha$ -olefin-based rubber and urethane  
20 resin, and to employ, as a water soluble solid material, at least one selected from the group consisting of dextrin and cyclodextrin, the water soluble solid material thus selected being subsequently distributed throughout the matrix thus selected.

25           The polishing pad comprising a matrix and a water soluble solid material which is distributed in the matrix can be manufactured according to the following

method. First of all, an organic material constituting the matrix is allowed to melt and, at the same time, a water soluble solid material is kneaded together with the organic material to obtain a raw material for the polishing pad. Then, if it is not required to perform the crosslinking of the organic material, this raw material is allowed to cool and worked into a disk-like sheet having a diameter of 600 mm for example, thereby obtaining a polishing pad having the water soluble solid material dispersed therein.

On the other hand, when the organic material is required to be crosslinked, a chemical crosslinking agent may be employed as required and kneaded together with the organic material, thus adding the chemical crosslinking agent to the raw material for the polishing pad. When the crosslinking is to be performed, the raw material is subjected to heating up to a predetermined temperature required for executing the crosslinking of the organic material or subjected to the irradiation of radiation, thereby allowing the crosslinking reaction of the organic material to take place. Thereafter, the raw material is cooled and worked, in the same manner as explained above, into a disk-like sheet having a diameter of 600 mm for example, thereby obtaining a polishing pad having the water soluble solid material dispersed therein.

In order to retain the slurry effectively,



trenches may be formed on the surface of the polishing pad. Although there is not any particular limitation with respect to the configuration of the trenches, it may be spiral, concentric, lattice-like or dot pattern-like configuration. Alternatively, the configuration of the trenches may be a composite of these configurations. These trenches can be formed on the surface of a sheet by cutting work for instance. Alternatively, a sheet may be molded by using a mold having trenches formed thereof, thereby forming the trenches simultaneous with the molding of the sheet.

The followings are explanation of one example of manufacturing a polishing pad wherein Pelprene S-2001 (trade name; thermoplastic polyester elastomer: Toyo Bouseki Co., Ltd.) was employed as an organic material, and Dexyparl (trade name; water soluble solid material  $\beta$ -cyclodextrin: Yokohama International Bio-Research Institute) of various average diameters were employed as a water soluble solid material.

First of all, the Pelprene S-2001 was heated at a temperature of 210°C to melt the Pelprene S-2001 and, at the same time, the Dexyparl employed as a water soluble solid material was added to the Pelprene S-2001, the resultant mixture being subsequently kneaded to obtain a raw material for the polishing pad. After being cooled, this raw material was worked into a disk-like sheet having a diameter of 600 mm, thus

manufacturing 32 kinds of polishing pads, i.e. No. 1  
through No. 32. Further, the same procedures as  
described above were repeated except that any kind of  
water soluble solid materials was not incorporated into  
5 the Pelprene S-2001, thereby manufacturing a polishing  
pad of No. 33. The thickness of these polishing pads  
was all set to about 2 mm.

Furthermore, a polyurethane polishing pad No. 34  
with cells having an average diameter of 20  $\mu\text{m}$  and  
10 distributed at a ratio of 3 vol.% based on the entire  
volume of the polishing pad was prepared.

The compression elastic modulus of these polishing  
pads No.1 through No.34 was all about 300 MPa.

Table 1

Polishing pad No.	Water soluble solid materials	
	Average diameter ( $\mu\text{m}$ )	Content (vol.%)
1	0.01	5
2	0.05	5
3	0.1	5
4	1	5
5	10	5
6	50	5
7	100	5
8	200	5
9	250	5
10	280	5
11	290	5
12	300	5
13	310	5
14	320	5
15	350	5
16	400	5
17	500	5
18	0.1	0.05
19	0.1	0.1
20	0.1	1
21	0.1	4
22	0.1	6
23	50	0.05
24	50	0.1
25	50	1
26	50	4
27	50	6
28	290	0.05
29	290	0.1
30	290	1
31	290	4
32	290	6
33	-	-
34	20	3

When the surface of the polishing pad No. 6 was observed by electron microscope, it was confirmed that the water soluble solid materials having a diameter of 300  $\mu\text{m}$  or more was not existed in an area of 1  $\text{cm}^2$ .

5 Namely, it was assumed that the particles of the water soluble solid material which were dispersed throughout the non-polishable matrix made of an organic material were not flocculated or not formed into a larger particle but were individually dispersed as single body  
10 in the matrix.

The polishing pads according this embodiment of the present invention can be suitably utilized in the formation of a Cu damascene wiring.

The procedures for the formation of this Cu  
15 damascene wiring will be explained with reference to FIGS. 2A to 2C.

First of all, as shown in FIG. 2A, a barrier metal film 105 and a wiring material film 106 were deposited on a semiconductor substrate 100 having semiconductor  
20 elements (not shown) formed thereon with an inorganic insulating film 101 and an insulating laminate films 103 and 104 being interposed therebetween.

The inorganic insulating film 101 was constructed such that a plug 102 formed of tungsten (W) was buried  
25 therein. The laminate insulating film includes a first insulating film 103 having a relative dielectric constant of less than 2.5, and a second insulating film

104 deposited on the first insulating film 103 and having a relative dielectric constant higher than that of the first insulating film 103.

5       The first insulating film 103 may be formed by using at least one selected from the group consisting of a film of a compound having a siloxane skeleton such as polysiloxane, hydrogen silsesquioxane, polymethylsiloxane and methylsilsesquioxane; a film containing mainly of an organic resin such  
10       as polyarylene ether, polybenzoxazole and polybenzocyclobutene; and a porous film such as a porous silica film. In this embodiment, the first insulating film 103 was formed by using LKD 5109 (JSR Co., Ltd.) to a thickness of 2000 angstroms.

15       The second insulating film 104 to be deposited on the first insulating film 103 functions as a cap insulating film and may be formed by using at least one insulating film having a relative dielectric constant of not less than 2.5 and selected from the group  
20       consisting, for example, of SiC, SiCH, SiCN, SiOC, SiN and SiOCH. The surface of the second insulating film 104 formed of these materials was hydrophobic. In this embodiment, the second insulating film 104 was formed by using black diamond (AMAT Co., Ltd.) to have  
25       a thickness of 1000 angstroms.

      The barrier metal film 105 and the wiring material film 106 were deposited the entire surface of

the substrate by sputtering method and plating after wiring trenches A was formed in the laminated insulating films 103 and 104. The barrier metal film 105 may be formed of a TaN film having a thickness of 200 angstroms, and the wiring material film 106 may be formed of a Cu film having a thickness of 5000 angstroms.

Incidentally, in the embodiment shown in FIG. 2A, although the insulating film on which the barrier metal film 105 and the wiring material film 106 were formed was constituted by a laminate structure including the first insulating film 103 and the second insulating film 104, this insulating film may be formed of a single layer of insulating film.

Next, the superfluous portions of the barrier metal film 105 and the wiring material film 106 were removed by CMP to expose the surface of the second insulating film 104. This CMP was performed in two steps, i.e. the removal of the wiring material film 106 (1st polishing), and the removal of the barrier metal film 105 (2nd polishing).

(1st polishing)

First of all, the CMP was performed under the following conditions to expose the surface of the barrier metal film 105 as shown in FIG. 2B.

Slurry: CMS7303/7304 (JSR Co., Ltd.)

Feeding rate of slurry: 250 cc/min;

Polishing pad: IC1000 (trade name; Rodel Nitta Co., Ltd.);

Load: 300 gf/cm<sup>2</sup>.

5 The rotational speed of the carrier and the turntable was both set to 100 rpm, and the polishing was continued for one minute. Since the polishing herein was stopped by the barrier metal film 105 and hence the hydrophobic second insulating film 104 was prevented from being exposed, the polishing was  
10 performed using a conventional polishing pad (IC1000). However, it is also possible to perform the polishing by using the polishing pad of the embodiments of the present invention.

(2nd polishing)

15 Next, part of the barrier metal film 105 which was disposed over the second insulating film 104 was removed by polishing to expose the surface of the second insulating film 104 (touch-up step) as explained below.

20 First of all, 34 kinds of polishing pads that had been manufactured as described above were subjected to conditioning by using a blocky diamond dresser #80 (Noritake Co., Ltd.).

Pressure of dresser: 100 gf/cm<sup>2</sup>;

25 Rotational speed of dresser/rotational speed of table: 20 rpm/20 rpm;

Flow rate of water: 300cc/min;

Conditioning period: 60 seconds.

The surface roughness of the field portion 13 of the surface of polishing pad after the conditioning was confined within the range of 1 to 3  $\mu\text{m}$ .

5           In the touch-up step, it is demanded that the scratches that have been generated on the polishing surface in the 1st polishing should be eliminated and at the same time, the erosion and step portions that have been generated in the 1st polishing should be  
10 reduced. These requirements can be achieved by the employment of a polishing pad wherein the surface thereof is suitably roughened and the matrix thereof has a suitable degree of hardness.

          A suitable degree of surface roughness can be  
15 provided by performing the conditioning of the surface. Generally, this can be achieved by working the surface of the matrix by using a diamond dresser where grain size thereof is confined to #50 to #500 or so, whereby the surface of the matrix is mechanically  
20 roughened or cut off to obtain a polishing pad (the field portion 13) having a surface roughness  $R_a$  of about 5  $\mu\text{m}$  or less. The surface condition of the polishing pad after this conditioning would become as shown in FIG. 1B.

25           Incidentally, in the case of conventional polishing pad where an average diameter of cells is relatively large or the volume ratio of cells in



the polishing pad is relatively high, the polishing pad is likely to be deformed during the dressing because of the reduction of the region of matrix in the polishing pad. As a result, it may become impossible to enable  
5 the polishing pad to sufficiently receive the mechanical action of the dresser, thus making it difficult to obtain an appropriate surface roughness corresponding to the grid size of the dresser. Whereas in the embodiments of the present invention, since the  
10 average diameter and volume ratio of the water soluble solid material to be dispersed throughout the matrix are confined within an appropriate range, it is made possible to easily obtain an appropriate surface roughness.

15 It is conceivable that the projected/recessed portion having a height or depth of 5  $\mu\text{m}$  or less and formed on the surface of the polishing pad by conditioning may be transformed as it is pressed against the polishing surface under the polishing  
20 pressure during the polishing step, thus substantially vanishing the existence of projected/recessed portion. However, once this projected/recessed portion is released from the polishing pressure, this projected/recessed portion restores its original  
25 configuration and act to quickly remove coarse abrasive grains having a particle diameter of 10  $\mu\text{m}$  or more and to enable it to retain only abrasive grains (effective

abrasive grains which contribute to the polishing)  
which are prevented from becoming coarse particles.

5 In order to minimize the scratch by the quick  
removal of coarse abrasive grains from the surface of  
polishing pad, the compression elastic modulus of the  
polishing pad should preferably be confined within the  
range of 100 to 600 MPa, more preferably 300 to  
600 MPa. As long as this condition of compression  
elastic modulus is satisfied, the polishing pad may be  
10 provided with suba 400 (trade name; Rodel Nitta Co.,  
Ltd.) as an underlayer.

By using the aforementioned polishing pads No. 1  
through No. 34 that have been undergone the  
conditioning as described above, the polishing was  
15 performed to expose the surface of the second  
insulating film 104 as shown in FIG. 2C.

In this polishing step, a semiconductor substrate  
302 sustained by a top ring 303 was press-contacted  
with a polishing pad 301 disposed on a turntable 300  
20 under a load of 300 gf/cm<sup>2</sup> as shown in FIG. 3, and the  
turntable 300 and the top ring 303 were both rotated at  
a rotational speed of 100 rpm. On this occasion,  
slurry 307 was fed from a slurry supply port 305 onto  
the polishing pad 301 at a flow rate of 200 cc/min,  
25 and the polishing was performed for one minute.  
Incidentally, FIG. 3 also shows a dresser 306 for  
carrying out the conditioning of the polishing pad 301

as well as a pure water supply port 304.

The slurry 307 was prepared as follows. Namely, 5% by weight of colloidal silica (primary particle diameter: 20 nm) was dispersed into pure water to obtain a dispersion. Further, KOH was added as a pH adjustor to the dispersion to adjust the pH of the dispersion to about 9. Furthermore, 0.1 wt% of H<sub>2</sub>O<sub>2</sub> as an oxidizing agent and 1 wt% of lactic acid as an additive were added to the dispersion. The resultant mixture was heated for 60 minutes at a temperature of 40°C to prepare the slurry wherein the flocculation of particles was accelerated. It was confirmed that the resultant slurry included coarse particles having a particle diameter of 1 μm or more at a ratio of 10,000/1 cc. In the case of a conventional slurry which is usually employed in the touch-up step, the ratio of coarse particles having a particle diameter of 1 μm or more is about 100/1 cc. In this embodiment, the polishing was performed using slurry containing a considerably large quantity of coarse particles, thus deliberately enhancing the severeness of slurry so as to investigate the effects of the polishing pad.

By a touch-up step, the wiring material film 106 was buried in the insulating film 104 to form a wiring having a line/space of: 0.1 μm/0.1 μm. The surface of this wiring was observed by using KLA2139 (KLA Co., Ltd.) to investigate the generation of scratches.

Further, the generation of erosion was also investigated by using ALPHA-STEP200 (TENCOR INSTRUMENTS Co., Ltd.). The results obtained are shown together with the polishing rate of the TaN film in the following Table 2.

Table 2

Polishing pad No.	Scratches (per 1 cm <sup>2</sup> )	Erosion (Å)	TaN polishing rate (Å/min.)
1	72	380	722
2	19	290	872
3	16	292	877
4	10	210	850
5	9	222	820
6	16	243	855
7	18	280	845
8	6	290	800
9	3	265	803
10	7	260	810
11	8	250	830
12	22	290	821
13	38	290	885
14	51	382	830
15	29	370	830
16	76	280	827
17	88	290	811
18	680	433	672
19	20	300	802
20	15	300	854
21	18	295	820
22	32	254	777
23	21	220	700
24	20	210	862
25	9	260	801
26	8	285	896
27	16	357	850
28	88	200	800
29	5	210	820
30	15	254	824
31	6	260	803
32	28	350	895
33	730	420	688
34	10	220	810

It should be noted that it is acceptable as a product if the number of scratches in an area of 1 cm<sup>2</sup> of the polishing surface is confined to not more than 20 and if the magnitude of erosion is confined to not higher than 300 angstroms. Further, in viewpoint of stability of polishing, the polishing rate of TaN is required to be not less than 800 angstroms/min.

As shown in Table 2, the polishing pads (Nos. 2-11, Nos. 19-21, Nos. 24-26, Nos. 29-31 and No. 34) which included a water soluble solid material or cells having an average diameter falling within the range of 0.05  $\mu$ m to 290  $\mu$ m and occupying a region ranging from 0.1% by volume to 5% by volume based on an entire volume of the polishing pad were found to satisfy all of the aforementioned criterions regarding the scratch and erosion.

In the cases of polishing pads (Nos. 4-11, Nos. 24-26 and Nos. 29-31) where an average diameter of the water soluble solid material was confined within the range of 1 to 290  $\mu$ m and the volume occupied by the water soluble solid material was confined within the range of 0.1% by volume to 5% by volume based on an entire volume of the polishing pad, especially excellent results were obtained. From the fact that it was possible to obtain especially excellent results by limiting the range of average particle diameter of the water soluble solid material to the aforementioned

range, it will be assumed that almost the same results would have been obtained even in the polishing pad where only cells are included therein and the average particle diameter thereof is controlled to fall within the aforementioned range (No. 34) or in the polishing pad where not only the water soluble solid material but also the cells are included therein and the average particle diameter thereof is controlled to fall within the aforementioned range. The polishing pads containing a water soluble solid material/cells having the aforementioned specific features can be employed until the residual thickness thereof becomes 0.3 mm or so.

In order to secure excellent results with respect to all of three features, i.e. scratch, erosion and polishing rate, the volume ratio of the water soluble solid material/cells dispersed in a matrix should preferably be confined within the range of 1 vol.% to 4 vol.% based on the entire volume of the polishing pad. Further, in order to secure a sufficient duration of life while retaining a suitable degree of conditioning speed of polishing pad, the average diameter of the water soluble solid material/cells should preferably be confined within the range of 1 to 100  $\mu\text{m}$ .

Whereas, if any one of conditions, i.e. average diameter and volume ratio of the water soluble solid

material/cells dispersed in the matrix falls outside the aforementioned ranges as defined in the embodiments of the present invention, it would become impossible to satisfy all of the aforementioned conditions with respect to the scratch, erosion and TaN polishing rate.

When a polishing pad where an average diameter of the water soluble solid material was less than 0.05  $\mu\text{m}$  (No. 1) was employed, not only the generation of scratches but also erosion became prominent and moreover, it was impossible to secure a sufficient degree of TaN polishing rate.

On the other hand, when a polishing pad where an average diameter of the water soluble solid material included in the matrix exceeded over 290  $\mu\text{m}$  (Nos. 12-17) was employed, the generation of scratches became prominent.

Further, if a polishing pad containing no water soluble solid material (No. 33) was employed, non-uniformity in wetting of slurry or pure water was resulted. When the long-term stability of polishing pad is taken into consideration, there is possibility that particles may be adhered onto the surface of dry polishing pad, thereby occurring the possibility of generating scratches. When the volume ratio of the water soluble solid material was less than 0.1 vol.% (Nos. 18, 23 and 28), it was impossible to expect the effect of improving the wettability of the polishing



pad. On the other hand, when the volume ratio of the water soluble solid material exceeded over 5 vol.% (Nos. 22, 27 and 32), the generation of scratches that had been once decreased was liable to increase again.

5 This can be attributed to the fact that since the water soluble solid material was permitted to excessively exist, a large number of trap sites for coarse particles exist on the surface of the polishing pad.

10 Further, as described above, the conditioning of the polishing pad is performed in such a way that the matrix is mechanically roughened or cut off. Therefore, if the polishing pad contains a large number of cells or water soluble solid material dispersed therein, part of the matrix is erased as a large mass, 15 thereby enabling recessed portions of as large as more than 5  $\mu\text{m}$  to be formed locally. Moreover, the speed of the conditioning may be caused to accelerate to shortening the life of the polishing pad.

20 Therefore, according to the embodiments of the present invention, an average diameter of the water soluble solid material/cells dispersed in the polishing pad is confined within the range of 0.05 to 290  $\mu\text{m}$  and the volume of the water soluble solid material/cells occupying the matrix is confined within the range of 25 0.1% by volume to 5% by volume based on the entire volume of the polishing pad.

Incidentally, the magnitude of roughness of

the fine projected/recessed portions to be formed on the surface of the polishing pad by the conditioning can be optionally selected by taking into consideration the particle size of the coarse particles existing in the slurry. As already explained above, the scratches generate on the polishing surface mainly due to the presence of coarse particles, so that if the polishing pad is incapable of holding such coarse particles, the generation of the scratches can be minimized.

Furthermore, the polishing treatment by using the polishing pads according to the embodiments of the present invention is also applicable to the formation of STI (Shallow Trench Isolation).

The procedures for the formation of this STI will be explained with reference to FIGS. 4A and 4B.

First of all, as shown in FIG. 4A, a trench was formed in a semiconductor substrate 200 having a CMP stopper film 201 formed thereon, and then, an insulating film 202 was deposited the entire resultant substrate. In this case, SiN can be employed as the CMP stopper film 201. As for the insulating film 202, it is possible to employ an SiO<sub>2</sub> film which can be formed by HDP (High Density Plasma) method. Alternatively, carbon (C) can be also employed as the CMP stopper film 201, and a coat type insulating film such as an organic SOG can be also employed as the insulating film 202. Carbon and SiN that can be

employed as the CMP stopper film 201 are hydrophobic in most cases. Moreover, since SiN has a  $\zeta$  potential which is approximately equivalent to isoelectric point, the CMP stopper film 201 is susceptible to the generation of scratch due to the polishing.

Next, a superfluous portion of the insulating film 202 is removed by CMP to expose the surface of the CMP stopper film 201 as shown in FIG. 4B. The conditions for this CMP were as follows. As for the polishing pad, a sheet of foamed polyester (No. 35) where cells having an average diameter of 200  $\mu\text{m}$  were distributed throughout the sheet (i.e. organic material) at ratio of 2 vol.% was prepared.

Slurry: 0.5 wt% ceria particle + 0.01 wt% polyacrylic acid + pure water (pH=6);

Flow rate of slurry: 300 cc/min;

Polishing pad: No. 35;

Load: 300 gf/cm<sup>2</sup>.

The rotational speed of the carrier and the turn table was both set to 100 rpm, and the polishing was continued for one minute.

For the purpose of comparison, the polishing of the insulating film 202 was performed under the same conditions except that IC1000 was substituted for the polishing pad No. 35. This IC1000 was constructed such that the cells having an average diameter of about 30  $\mu\text{m}$  were distributed throughout the polishing pad at

a ratio of about 30 vol.% and the compression elastic modulus thereof was about 290 MPa.

Then, the surface of the stopper film 201 was observed after this polishing treatment by using  
5 KLA2139 (KLA Co., Ltd.). As a result, it was recognized that while the number of scratches on the surface of the stopper film 201 was 88/wafer when the IC1000 was employed, the number of scratches was reduced to 2/wafer when the polishing pad No. 35 was  
10 employed. It was confirmed from these facts that it was possible to greatly minimize the generation of scratch in the polishing process by using the polishing pads according to the embodiments of the present invention.

15 Incidentally, even when the polishing pads of Nos. 2-11, 19-21, 24-26, 29-31 and 34 are employed in the polishing of the insulating film 202, almost the same effects as described above are expected to be obtained.

20 Further, as long as the average diameter and the dispersion ratio are confined within the aforementioned ranges, the cells may be co-existed with the water soluble solid material in the matrix without substantially affecting the excellent effects that can  
25 be obtained as described above.

As described above, according to the embodiments of the present invention, it is possible to provide

a polishing pad which is capable of polishing  
a treating surface at a high speed while making it  
possible to minimize the generation of scratch and  
erosion, and, at the same time, to provide a method of  
5 manufacturing a semiconductor device employing such  
a polishing pad.

According to the present invention, it is possible  
to manufacture a semiconductor device of high  
performance and high speed, which is provided with  
10 wirings having a design rule of 0.1  $\mu\text{m}$  or less which  
will be demanded in wirings of the next generation, and  
therefore, the present invention would be very valuable  
in industrial viewpoint.

Additional advantages and modifications will  
15 readily occur to those skilled in the art. Therefore,  
the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
shown and described herein. Accordingly, various  
modifications may be made without departing from the  
20 spirit or scope of the general inventive concept as  
defined by the appended claims and their equivalents.